HYDROGEN
Safety Panel

Safety Planning for Hydrogen and Fuel Cell Projects

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PNNL-SA-132444

Webinar Outline

Part 1 Safety Planning

- Introduction
- Background on the Hydrogen Safety Panel
- Safety Planning
- Learnings from California HSP Reviews and Activities
- Hydrogen Safety Resources
- Q&A

Part 2 Safety Considerations

- Properties of Hydrogen
- Primary Codes and Standards
- Fundamental Safety Considerations
- Q&A

Introduction

General Funding Opportunity GFO-17-602

GFO-17-602 will provide grant funds for projects that will design, engineer, construct, install, test, operate, and maintain a **100 percent renewable hydrogen facilities in California**.

The facilities will:

- Produce and provide 100 percent renewable hydrogen from in-state renewable resources
- Distribute, deliver, and supply a portion or all of the network of hydrogen refueling stations in California

GFO Project Safety Activities

Safe practices for the production, storage, distribution and use of hydrogen are essential to establish public confidence and for reducing barriers to widespread acceptance of hydrogen technologies.

GFO-17-602 Safety Planning Activities and Requirements

- Safety planning Webinar and pre-submission consultation
- Submission of a hydrogen safety plan
- HSP safety plan assessment
- Post award activities
  - HSP review of project design
  - Release and incident reporting
  - Post startup interviews

PNNL's Hydrogen Safety Resources

Hydrogen Safety Panel (HSP)

- Identify Safety-Related Technical Data Gaps
- Review Safety Plans and Project Designs
- Perform Safety Evaluation Site Visits
- Provide Technical Oversight for Other Program Areas

Hydrogen Tools *Web Portal* (*http://h2tools.org*)

- Hydrogen Facts, Training, Forums, HyARC Tools
- Hydrogen Lessons Learned, Best Practices, Workspaces

Emergency Response Training Resources

- Online Awareness Training
- Operations-Level Classroom/Hands-On Training
- National Hydrogen and Fuel Cell Emergency Response Training Resource

Background on the Hydrogen Safety Panel

Introducing the **Hydrogen Safety Panel (HSP)**

Experienced, Independent, Trusted Expertise

The HSP promotes safe operation, handling, and use of H_2

- Formed in 2003
- **400+ yrs** combined experience
- **Over 480 H_2 safety reviews completed** – H_2 fueling, auxiliary power, backup power, CHP, portable power, and lab R&D
- White papers, industry guides, guidance on application of codes and standards
- **H_2 safety knowledge shared through the H_2 Tools Portal** (h2tools.org)

Some of the fire officials and hydrogen experts that comprise the Hydrogen Safety Panel (24th meeting, 2017, Cambridge, MA)

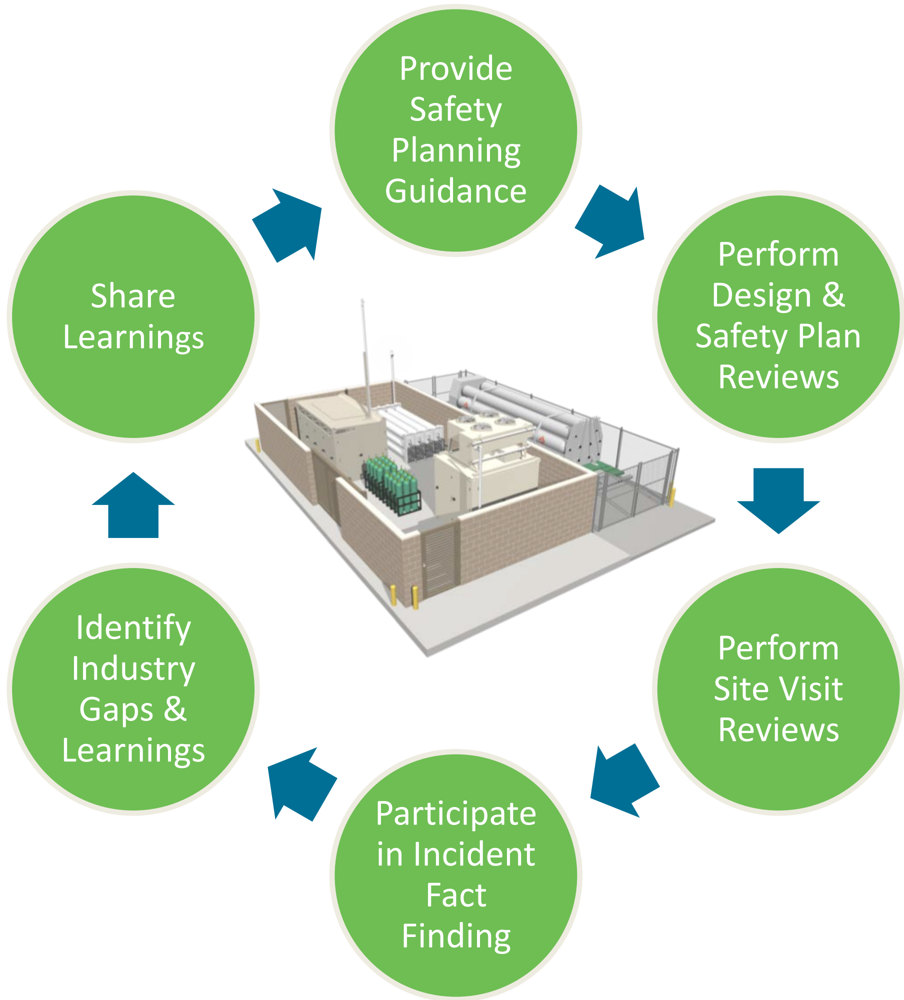
More information is available at http://www.h2tools.org/hsp

Hydrogen Safety Panel: Objective and Activities

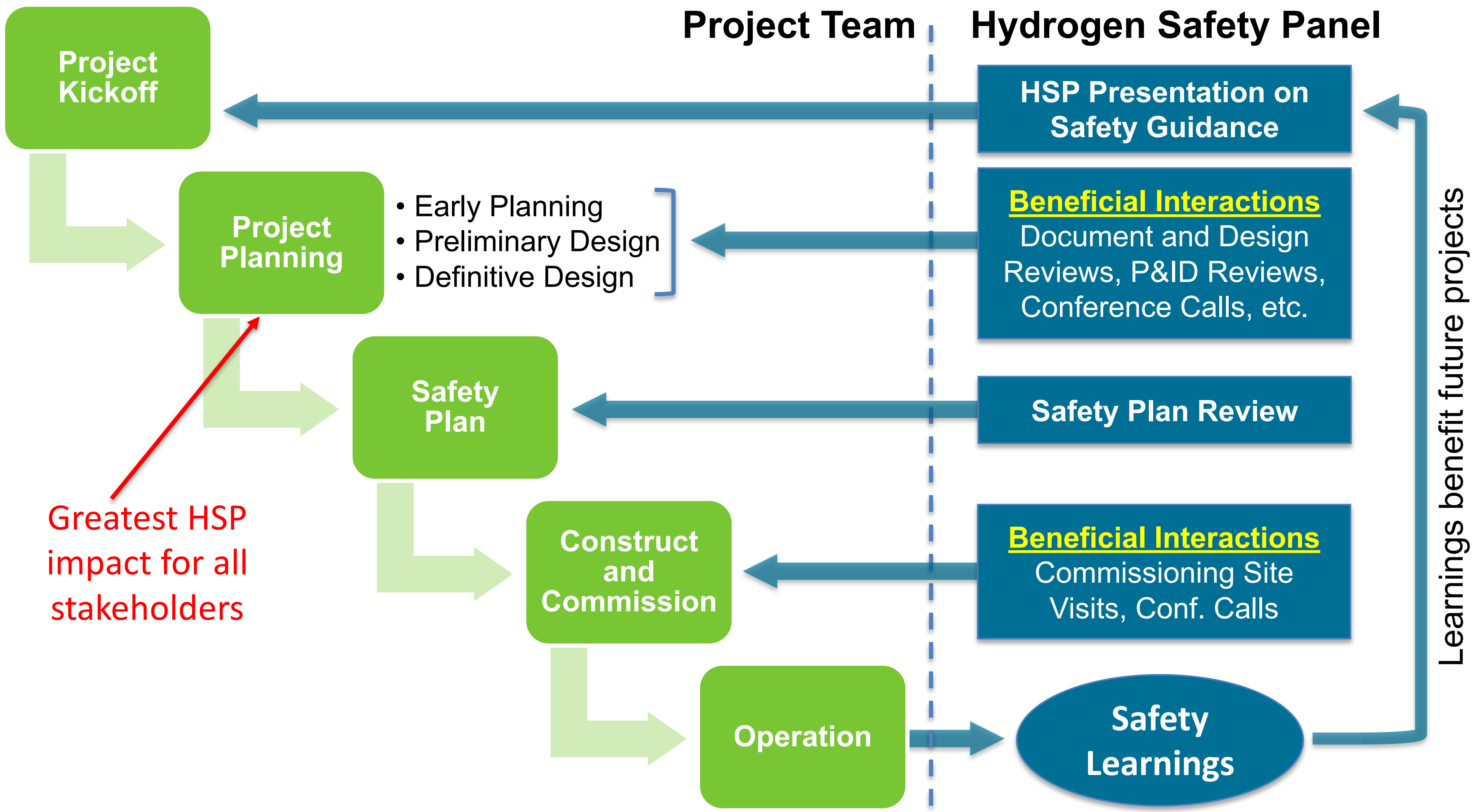
The purpose of the HSP is to share the benefits of extensive experience by providing suggestions and recommendations pertaining to the safe handling and use of hydrogen.

Objective: Enable the safe and timely transition to hydrogen technologies by:

- Participating in hydrogen projects to ensure safety is adequately considered
- Providing expertise and recommendations to stakeholders and assist with identifying safety-related gaps, best practices and lessons learned

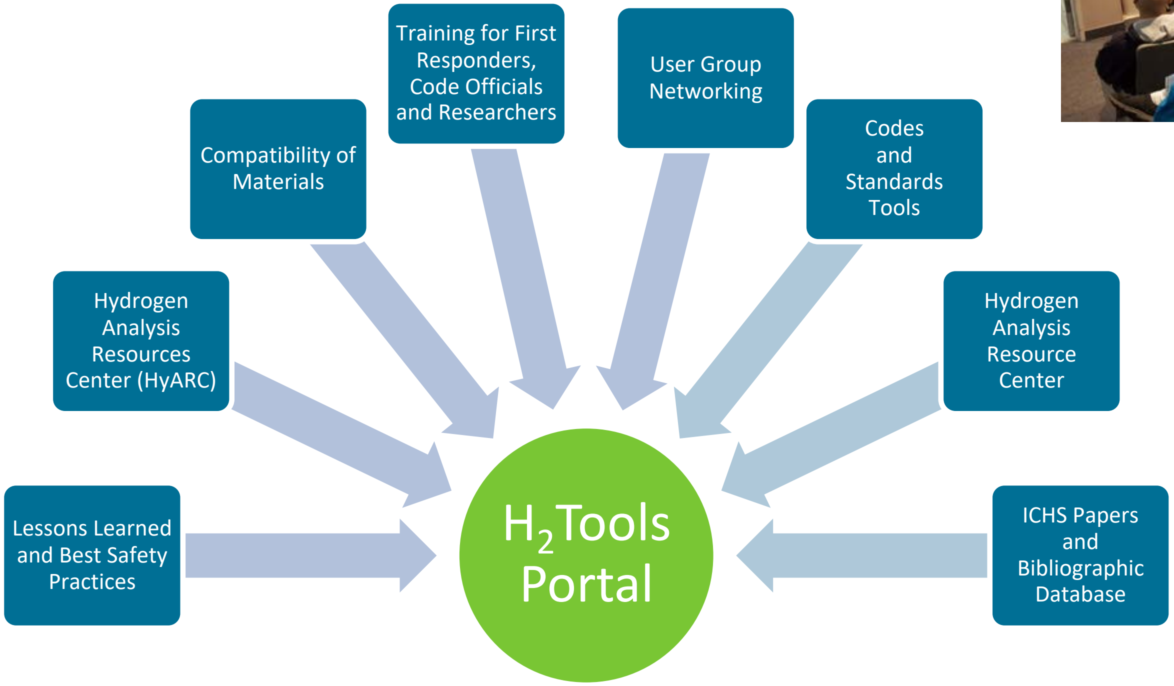


Optimal HSP Project Interaction



Sharing Safety Learnings

- Project Interaction
- Outreach and Presentations
- Hydrogen Tools Portal (http://h2tools.org)



Energy Exchange[SM]
Connect • Collaborate • Conserve
An educated approach to resiliency
U.S. Department of Energy Federal Energy Management Program

California Fuel Cell Partnership
DRIVING FOR THE FUTURE

NFPA® CONFERENCE & EXPO

Impact of the HSP's Activities

- Serves as a non-regulatory, objective and neutral resource
- Sees the "big picture"
  - Shares learnings
  - Identifies gaps
- Can help reduce costs
  - Over engineering resulting in unnecessary features
  - Delayed approvals
  - Missed safety considerations/features
- A group with diverse experience can respond with a balanced solution to questions, problems and issues
- Can aid in avoiding repeating costly mistakes among disparate project proponents
- Can help project proponents to avoid industry impacting incidents
- **Helps establish customer/stakeholder/public confidence**

Safety Planning

The Safety Challenge

- Safety issues must be addressed for successful hydrogen technology acceptance and deployment
- Safety issues can be a ‘deal breaker’
- Hydrogen technology stakeholders may not be able to identify and effectively address all safety issues
- Stakeholders benefit from an independent and experienced hydrogen safety review (ISR) resource involved in early design and safety planning activities
- Hydrogen Safety Panel feedback and learnings help individual projects and the entire industry remove barriers and ease future deployments

Primary Goals

The goals of safety planning are to:

- identify hazards,
- evaluate risks by considering the likelihood and severity/consequence of an incident associated with the hazards, and
- minimize the risks associated with a project

To achieve these goals, various hazard analysis and risk assessment techniques are used, in conjunction with safety reviews.

Safety planning should be an integral part of the design and operation of a system. Safety approvals should not be after thoughts or final hurdles to be overcome before a system can become operational.

Guidance for Effective Safety Plans

The project safety planning process is meant to:

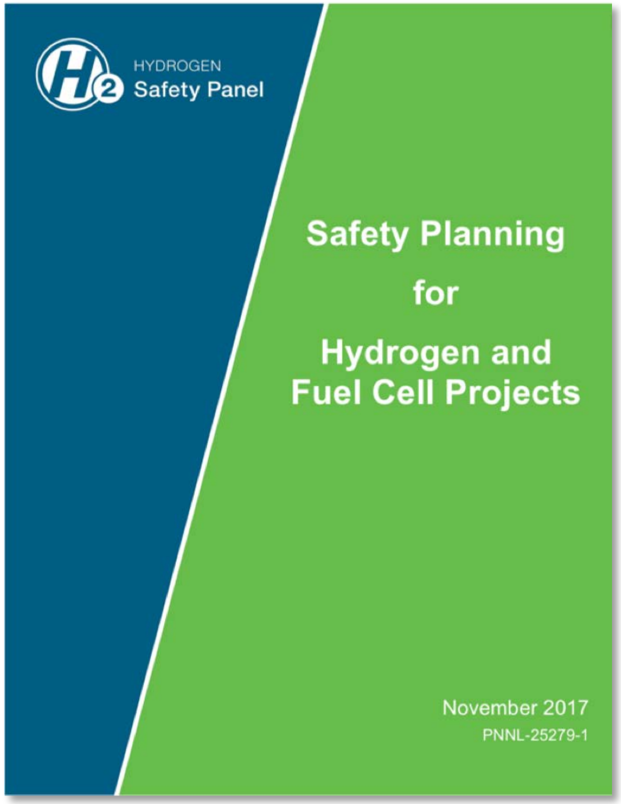
- help identify and avoid potential hydrogen-related incidents
- generate a effective safety plan that will serve as a guide for the safe conduct of all project work

A safety plan should:

- use a graded approach based on level of risk and complexity
- cover all operational work being conducted with particular emphasis on the aspects involving hydrogen and hazardous materials handling

Safety Planning Guidance

Table of Contents



Guidance document is available for download at:
https://www.h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017.pdf

Focusing on the Hazards

Potential hazards in any work, process or system should be identified, analyzed and eliminated or mitigated as part of sound safety planning. **In general, a good safety plan identifies:**

- immediate (primary) failure modes
- secondary failure modes that may come about as a result of other failures

For effective safety planning, an attempt is made to identify all conceivable failures, from catastrophic failures to benign collateral failures. Identification and discussion of perceived benign failures may lead to the identification of more serious potential failures.

NFPA 2 requires a hazard analysis to be conducted on every hydrogen fueling system installation by a qualified engineer(s) with proven expertise in hydrogen fueling systems, installations, and hazard analysis techniques.

Identification of Safety Vulnerabilities (ISV)

Assessment of the potential hazards associated with work at any scale from laboratory to operations begins with the identification of an appropriate assessment technique. The ISV is the formal means by which potential safety issues associated with laboratory or process steps, materials, equipment, operations, facilities and personnel are identified. The plan should describe:

- the ISV method that is used for this project
- who leads and stewards the use and results of the ISV process
- significant accident scenarios identified (e.g. higher consequence, higher frequency)
- significant vulnerabilities (risks) identified
- safety critical equipment

Common ISV Methods

Common methods employed by those involved in systems safety today include, but are not limited to:

- Hazard and operability studies (HAZOPs)
- Failure modes effects and criticality analysis (FMECA)
- Preliminary hazards analysis (PHA)
- Fault tree analysis (FTA)
- Event tree analysis.

Standard designs that have been analyzed by recognized methodology need not be studied each and every time such an installation occurs. Rather, site-specific elements that are unique to the installation should be reviewed in concert with the analysis performed on the standard system to ensure that the standard design has not been altered in a way that would negatively affect the hazard analysis. (NFPA 2)

The Hydrogen Safety Panel would also like to see two questions answered in the Safety Plan:

- *What hazard associated with this project is most likely to occur?*
- *What hazard associated with this project has the potential to result in the worst consequence?*

Applicants desiring to use previous project ISVs should provide information from those documents to the HSP for this submission along with site specific considerations. Additionally, whenever a change to a standard design occurs, the ISV should be revisited.

Codes and Standards

Designs must meet the relevant safety codes and standards for installation in the target location, including the applicable parts of the following:

- NFPA 2, Hydrogen Technologies Code, 2016 Edition
- NFPA 70, National Electrical Code®
- ASME B31.3, Process Piping; or B31.12, Hydrogen Piping and Pipelines
- ASME Boiler and Pressure Vessel Code (BPV)
- International Fire and Building Codes

Compliance with applicable codes and standards is essential for ensuring public confidence in commercial projects, particularly for those deploying new technologies.

Other Important Issues for Safety

- **Management of Change (MOC)** - The safety plan should describe the method that will be used to review proposed changes to materials, technology, equipment, procedures, personnel and facility operation for their effect on safety vulnerabilities.

- **Compatibility of Materials** - Materials of construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen <u>at the intended operating conditions</u>. How has the project validated the performance of materials that may be exposed to hydrogen?

Other Relevant Questions…

- Who are the authorities having jurisdiction, and to what degree have they been involved in the design and installation of equipment for this project?
- Was there any special permitting and/or certification that was required?
- Has a third-party review or certification of any components, sub-systems, systems or products been considered and performed?

Additional Documentation

To give a reviewer the best opportunity to judge the quality of the safety plan, the submittal should include, but not be limited to, the following additional documentation, as applicable:

<table>
<tr><th>Minimum Required</th><th>Desired if Available</th></tr>
<tr><td>Flow diagram showing equipment</td><td>Flow diagram showing components including equipment, and safety related devices such as block valves, instruments and relief devices. See Appendix V for an example.</td></tr>
<tr><td>Preliminary functional description for equipment shown in the flow diagram</td><td>Design or functional description for each component in the diagram</td></tr>
<tr><td colspan="2">Codes and standards compliance discussion, including information on alternative means and methods used to meet requirements</td></tr>
<tr><td>Preliminary layout</td><td>Layout of the system including as applicable:
a) Site plan showing distances to property lines and other separation distances
b) Vehicle access to/from the equipment (including delivery vehicle)
c) Hydrogen vent system considerations, including the number of vent stacks, and pressure/flow design of each stack
d) Electrical classification and ignition source control
e) Ventilation requirements for any enclosed spaces</td></tr>
<tr><td colspan="2">Critical safety and shutdown table identifying shutdown events described in the ISV or risk reduction plan, including automatic and manual shutdowns, loss of electricity, and fail-safe features – see Appendix V for an example.</td></tr>
</table>

Working with First Responders

Preplanning

- Project teams and and facility owners should work with local first responders to assist in their preplanning activities. This should include a tour of the hydrogen facilities with focused attention on safety features and emergency shutoffs.

Training

- Training of emergency response personnel should be a high priority to ensure that these personnel understand how to properly respond to a hydrogen incident.
- A variety of resources are available to assist with this training (see the resource lists at the end of this presentation).

Equipment

- A hydrogen fire is often difficult to detect without a thermal imaging camera or flame detector. Ensure that the local first responders have one available for their use.

Use the Checklist!

Appendix III of the safety guidance document includes a checklist to help the project team verify that their safety plan addresses the important elements.

Its use is highly recommended!

Element	The Safety Plan Should Describe
Description of Work	• Nature of the work being performed
Organizational Policies and Procedures	• Application of safety-related policies and procedures to the work being performed
Hydrogen and Fuel Cell Experience	• How previous organizational experience with hydrogen, fuel cell and related work is applied to this project
Safety Reviews	• Applicable safety reviews beyond the ISV described below
Identification of Safety Vulnerabilities (ISV)	• What is the ISV methodology applied to this project, such as FMEA, What If, HAZOP, Checklist, Fault Tree, Event Tree, Probabilistic Risk Assessment, or other method • Who leads and stewards the use of the ISV methodology • Significant accident scenarios identified • Significant vulnerabilities identified • Safety critical equipment • Storage and handling of hazardous materials and related topics o ignition sources, explosion hazards o materials interactions o possible leakage and accumulation o detection • Hydrogen handling systems o supply, storage, and distribution systems o volumes, pressures, estimated use rates • Additional Documentation provided (see section below)
Risk Reduction Plan	• Prevention and mitigation measures for significant vulnerabilities
Procedures	• Procedures applicable for the location and performance of the work including sample handling and transport • Operating steps that need to be written for the particular project: critical variables, their acceptable ranges, and responses to deviations from them

Learnings from California HSP Reviews and Activities

HSP Activities for CA H_2 Fueling Stations

- California 2016 hydrogen fueling station GFO applicant safety plan reviews
- March 2017 HSP visit to 7 California locations

South San Francisco

Woodside and Long Beach

2016 GFO Call for H_2 Fueling Stations

Contracted by the California Energy Commission (CEC) to support the construction of new hydrogen fueling stations through the following services

- Provided guidance for preparing safety plans
- Participated in pre-award safety consultation for applicants
- Reviewed safety plans submitted by 12 applicants to California's GFO-15-605
- Provided comments to the CEC in support of award decisions
- Additional support to be provided until funded stations have been complete for three years

Safety Plan Reviews of GFO-15-605 Applications

- Safety plans for 12 applications were reviewed
- Up to 35 locations per application
- Safety plans, narrative documents and site information reviewed
- Review report provided for each applicant (can be viewed at https://h2tools.org/hsp/reviews - screenshot on right)
- The reviews and process were evaluated for potential learnings
- The safety planning guidance document will be updated to benefit future station projects

Safety Resources and Reviews

SAFETY PLANNING RESOURCES

- Safety Planning for Hydrogen and Fuel Cell Projects - Latest Version
  - Safety Planning for Hydrogen and Fuel Cell Projects - March 2016
- Safety-Planning-for-the-2014-2016-H-Prize-Competition.pdf
- Safety Planning Guidance for Hydrogen and Fuel Cell Projects - April 2010 (DOE projects)
- Hydrogen Safety Checklist

SAFETY PANEL REVIEWS

Title	Activity Type	Project Number	Date	Links
Everfuel Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
A3L/Next Hydrogen Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
Shell Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
ITM Power/Greenlight Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
ITM Power/Linde Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
Jensen Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
Hydrogen-XT Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
Air Liquide Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
FirstElement Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
HTEC Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
Air Products Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download
StratosFuel Hydrogen Fueling Station	Safety Plan Review	GFO-15-605	December 2016	Download

Technical Learnings from GFO-15-605 Reviews

- **Equipment siting** from property lines is not in accordance with NFPA 2 requirements
- **Courtyards** provided with four walls is not in accordance with NFPA 2 requirements
- **Certification** of unlisted equipment needs to be verified against all applicable standards and requirements
- It is unclear how the performance and reliability of **control equipment** for safety systems is validated

Process Learnings from GFO-15-605 Reviews

- Detailed project-specific information is needed to perform a thorough evaluation
  - Timing of the review (application stage) may have affected the availability of important information
  - Utilizing the HSP for review at a later stage, perhaps early in the definitive design process, could result in a more impactful review and confidence in the project team's safety approach
- The project safety plan should cover all project partners and project phases (design, commissioning, operation and maintenance)

March 2017 CA Stakeholder Meetings

- Meetings were held at 7 California locations to discuss fueling station deployments
- Attendance included:
  - hydrogen fueling station builders
  - code officials
  - other state officials and stakeholders
- Goal – discuss safety issues and lessons learned from recent station deployments
- Resulted in over 100 pages of notes which were subsequently reviewed, categorized and binned
- Results were assembled into learnings and further reviewed by the entire HSP

Feedback and Learnings from CA Meetings

Items were organized into topical areas

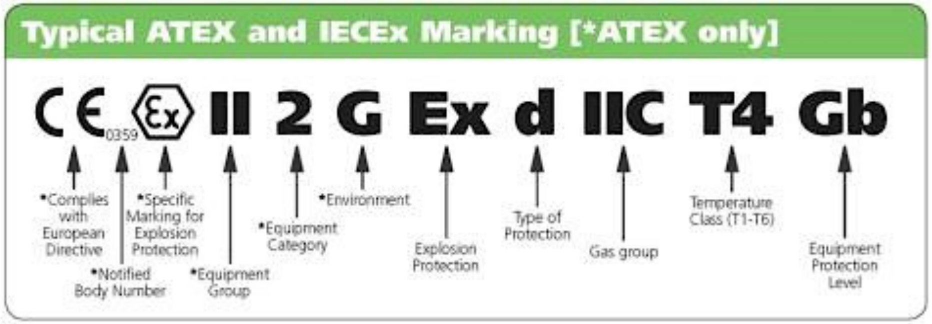
- Separation distances
- Certification
- Emergency shutdown systems
- Permitting
- Training
- NFPA 2 considerations
- Public
- Miscellaneous

Separation Distances

- Comparisons between hydrogen and other fuels need to be correct, especially when considering separation distances
- Some code officials (incorrectly) felt strongly that installing hydrogen tanks underground would fully address separation distances issues, including the future need for liquid hydrogen

Certification

- The lack of listed hydrogen equipment may result in an increase in facility costs (third-party certification is needed for each new station)
- Hydrogen equipment having non-US listing/certifications may not be accepted by AHJs in the US



Typical CE ATEX Label

Emergency Shutdown Systems (ESD)

- Projects should utilize control equipment for safety functions that has a high reliability and performance capabilities consistent with its intended use
- Station operators experience with false alarms of the flame detectors suggest that more reliable triple-IR detectors may be a better option
- There were variations between sites on how system alarms and shutdown functions operated, which could cause confusion for first responders

Permitting

- Required prescriptive safety features should not be solely credited for establishing equivalent safety of unmet requirements
- Code officials may not be aware of the sources of independent information available to help them with their review
- Most code officials on their first hydrogen project did not reach out to their more experienced counterparts in other jurisdictions
  - Code officials that reviewed station designs were overwhelmingly supportive of allowing others to reach out to them for advice and support
- Permit applications should be comprised of succinct and accurate information to facilitate the code official’s review

Training

- Lack of first responder (FR) training for new station locations
- Expand FR training beyond jurisdictions having a station
- Training for first responders and code officials should be in "fire-related language"
- Code official training before the design review stage may be beneficial
- Attendees will receive maximum value if they are involved in or affected by a hydrogen project

Miscellaneous Observations and Learnings

- The sequence of operations (functions and shutdowns) for normal and off-normal events wasn't communicated well between station providers and operators/owners/first responders
- Safety information should be made available at an obvious location at the facility to assist in emergency response and for training first responders
- Code officials highlighted the benefits of NFPA 2 annex material.

Hydrogen Safety Resources

Hydrogen Tools

A Transformative Step Towards Hydrogen Adoption

CENTRALIZED LOCATION organizes current H_2 resources in one robust location—including many proven tools, with plans for adding future content

FOCUSED CONTENT tailored to the specialized needs of H_2 user groups

RESPONSIVE DESIGN enables H_2 safety work across both desktop and mobile devices

TRUSTED COMMUNITIES fostered through social networking around H_2 subject matter expertise

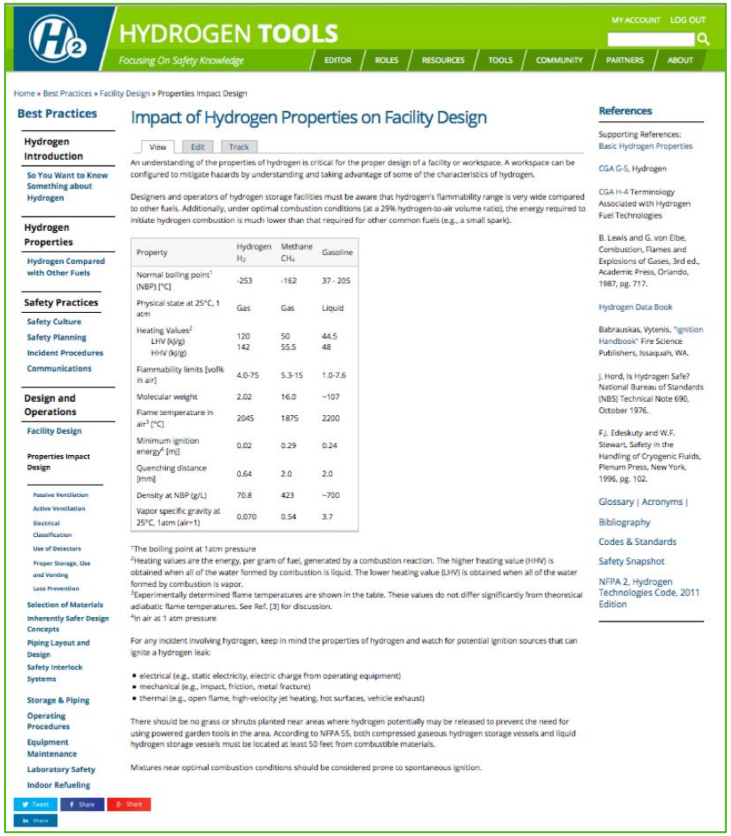
EXPANDABLE FORMAT built with frequently requested future feature sets in mind

http://**h2tools**.org

› **Credible** and **reliable** safety information from a **trustworthy** source

H2tools.org/bestpractices
…Sharing Experience, Applying Best Practices

- Introduction to Hydrogen
  - So you want to know something about hydrogen?
- Hydrogen Properties
  - Hydrogen compared with other fuels
- Safety Practices
  - Safety culture
  - Safety planning
  - Incident procedures
  - Communications
- Design and Operations
  - Facility design considerations
  - Storage and piping
  - Operating procedures
  - Equipment maintenance
  - Laboratory safety
  - Indoor refueling of forklifts



HYDROGEN TOOLS
Focusing On Safety Knowledge
MY ACCOUNT LOG OUT
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Home » Best Practices » Facility Design » Properties Impact Design

Best Practices

Hydrogen Introduction
- So You Want to Know Something about Hydrogen

Hydrogen Properties
- Hydrogen Compared with Other Fuels

Safety Practices
- Safety Culture
- Safety Planning
- Incident Procedures
- Communications

Design and Operations
- Facility Design
  - Properties Impact Design
    - Passive Ventilation
    - Active Ventilation
    - Electrical Classification
    - Use of Detectors
    - Proper Storage, Use and Venting
    - Loss Prevention
  - Selection of Materials
  - Inherently Safer Design Concepts
  - Piping Layout and Design
  - Safety Interlock Systems
- Storage & Piping
- Operating Procedures
- Equipment Maintenance
- Laboratory Safety
- Indoor Refueling

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Impact of Hydrogen Properties on Facility Design

View | Edit | Track

An understanding of the properties of hydrogen is critical for the proper design of a facility or workspace. A workspace can be configured to mitigate hazards by understanding and taking advantage of some of the characteristics of hydrogen.

Designers and operators of hydrogen storage facilities must be aware that hydrogen's flammability range is very wide compared to other fuels. Additionally, under optimal combustion conditions (at a 29% hydrogen-to-air volume ratio), the energy required to initiate hydrogen combustion is much lower than that required for other common fuels (e.g., a small spark).

Property	Hydrogen H_2	Methane CH_4	Gasoline
Normal boiling point[1] (NBP) [°C]	-253	-162	37 - 205
Physical state at 25°C, 1 atm	Gas	Gas	Liquid
Heating Values[2] LHV (kJ/g) HHV (kJ/g)	120 142	50 55.5	44.5 48
Flammability limits [vol% in air]	4.0-75	5.3-15	1.0-7.6
Molecular weight	2.02	16.0	~107
Flame temperature in air[3] [°C]	2045	1875	2200
Minimum ignition energy[4] [mJ]	0.02	0.29	0.24
Quenching distance [mm]	0.64	2.0	2.0
Density at NBP (g/L)	70.8	423	~700
Vapor specific gravity at 25°C, 1atm (air=1)	0.070	0.54	3.7

[1]The boiling point at 1atm pressure
[2]Heating values are the energy, per gram of fuel, generated by a combustion reaction. The higher heating value (HHV) is obtained when all of the water formed by combustion is liquid. The lower heating value (LHV) is obtained when all of the water formed by combustion is vapor.
[3]Experimentally determined flame temperatures are shown in the table. These values do not differ significantly from theoretical adiabatic flame temperatures. See Ref. [3] for discussion.
[4]In air at 1 atm pressure

For any incident involving hydrogen, keep in mind the properties of hydrogen and watch for potential ignition sources that can ignite a hydrogen leak:

- electrical (e.g., static electricity, electric charge from operating equipment)
- mechanical (e.g., impact, friction, metal fracture)
- thermal (e.g., open flame, high-velocity jet heating, hot surfaces, vehicle exhaust)

There should be no grass or shrubs planted near areas where hydrogen potentially may be released to prevent the need for using powered garden tools in the area. According to NFPA 55, both compressed gaseous hydrogen storage vessels and liquid hydrogen storage vessels must be located at least 50 feet from combustible materials.

Mixtures near optimal combustion conditions should be considered prone to spontaneous ignition.

References

Supporting References: Basic Hydrogen Properties

CGA G-5, Hydrogen

CGA H-4 Terminology Associated with Hydrogen Fuel Technologies

B. Lewis and G. von Elbe, Combustion, Flames and Explosions of Gases, 3rd ed., Academic Press, Orlando, 1987, pg. 717.

Hydrogen Data Book

Babrauskas, Vytenis. "Ignition Handbook" Fire Science Publishers, Issaquah, WA.

J. Hord, Is Hydrogen Safe? National Bureau of Standards (NBS) Technical Note 690, October 1976.

F.J. Edeskuty and W.F. Stewart, Safety in the Handling of Cryogenic Fluids, Plenum Press, New York, 1996, pg. 102.

Glossary | Acronyms |

Bibliography

Codes & Standards

Safety Snapshot

NFPA 2, Hydrogen Technologies Code, 2011 Edition

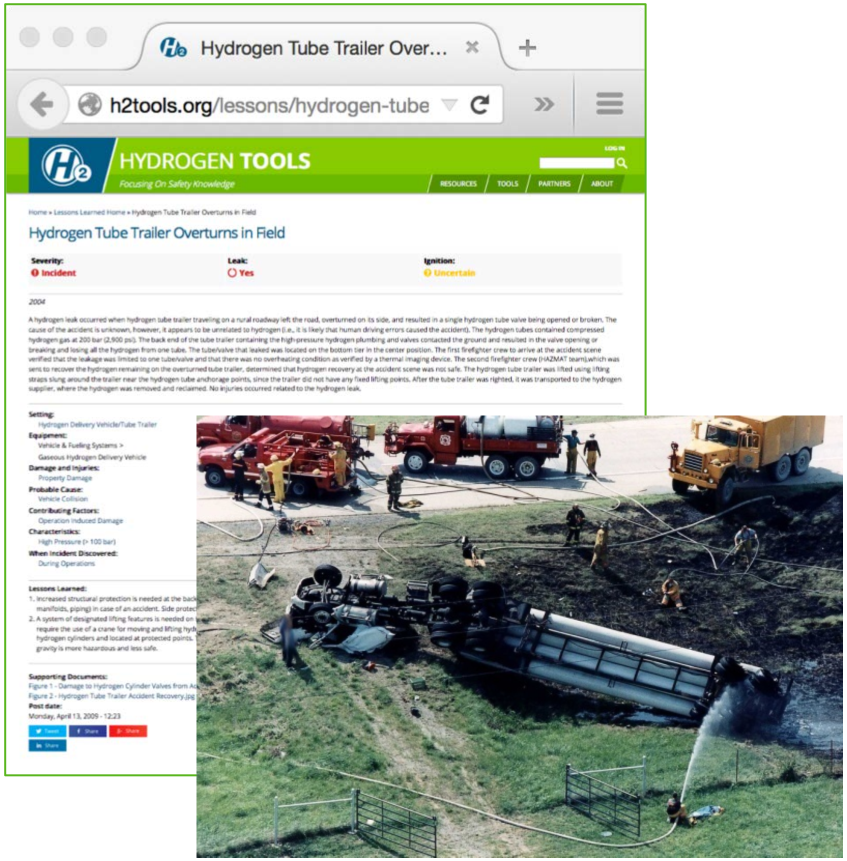
Safety events from "H2incidents.org" illustrate what can go wrong if best practices are not followed.

URL: http://h2tools.org/bestpractices

H2tools.org/lessons
…Capturing the Event, Focusing on Lessons Learned

Each safety event record contains:

- Description
- Severity (Was hydrogen released? Was there ignition?)
- Setting
- Equipment
- Characteristics (High pressure? Low temperature?)
- Damage and Injuries
- Probable Cause(s)
- Contributing Factors
- Lessons Learned/Suggestions for Avoidance/Mitigation Steps Taken



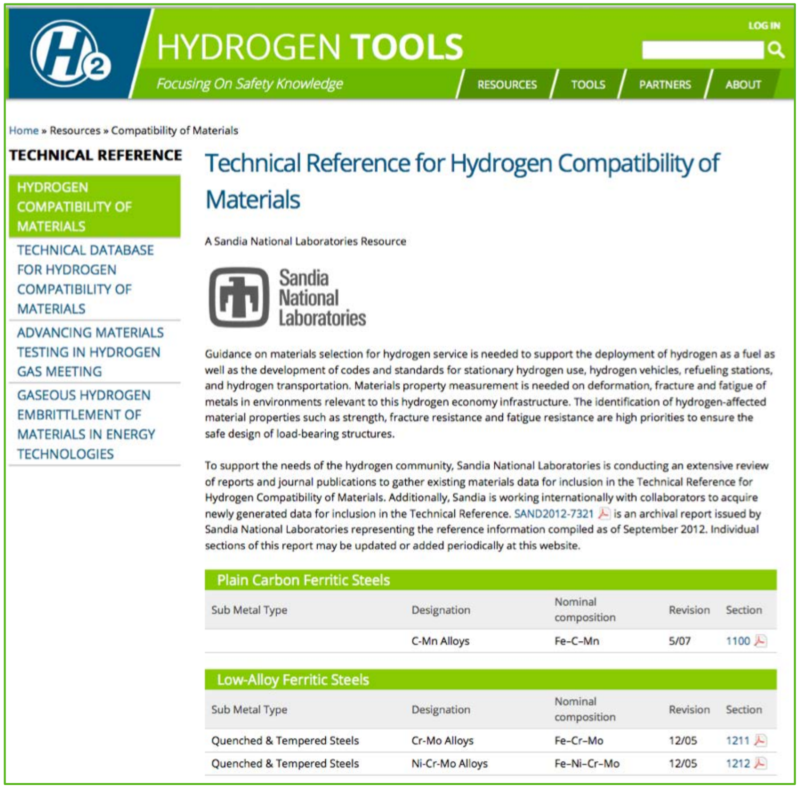
Tube trailer rollover

URL: http://h2tools.org/lessons

Technical Reference for Hydrogen Compatibility of Materials

Consists of material specific chapters (as individual PDF files) summarizing mechanical-property data from journal publications and technical reports

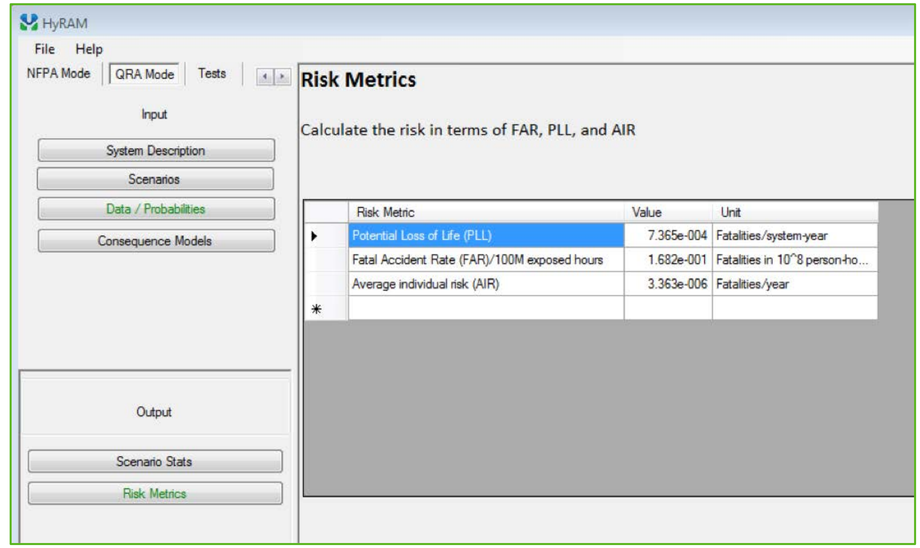
- Plain Carbon Ferritic Steels
- Low-Alloy Ferritic Steels
- High-Alloy Ferritic Steels
- Austenitic Steels
- Aluminum Alloys
- Copper Alloys
- Nickel Alloys
- Nonmetals



URL: http://h2tools.org/tech-ref/technical-reference-for-hydrogen-compatibility-of-materials

Quantitative Risk Assessment

- Developed toolkit to enable integrated probabilistic and deterministic modeling
  - Relevant hydrogen hazards (thermal, mechanical)
  - Probabilistic models (traditional QRA models) & hydrogen-specific component data
  - Hydrogen phenomena (gas release, heat flux, overpressure)
- Variable Users
  - High level, generic insights (e.g., for C&S developers, regulators)
  - Detailed, site-specific insights (e.g., for AHJs, station designers)
- Currently, two interfaces (views):
  - **“QRA mode”** and **“Physics mode”**
  - Planned “performance-based design” mode for targeted analyses



HYRAM
HYDROGEN RISK ASSESSMENT MODELS

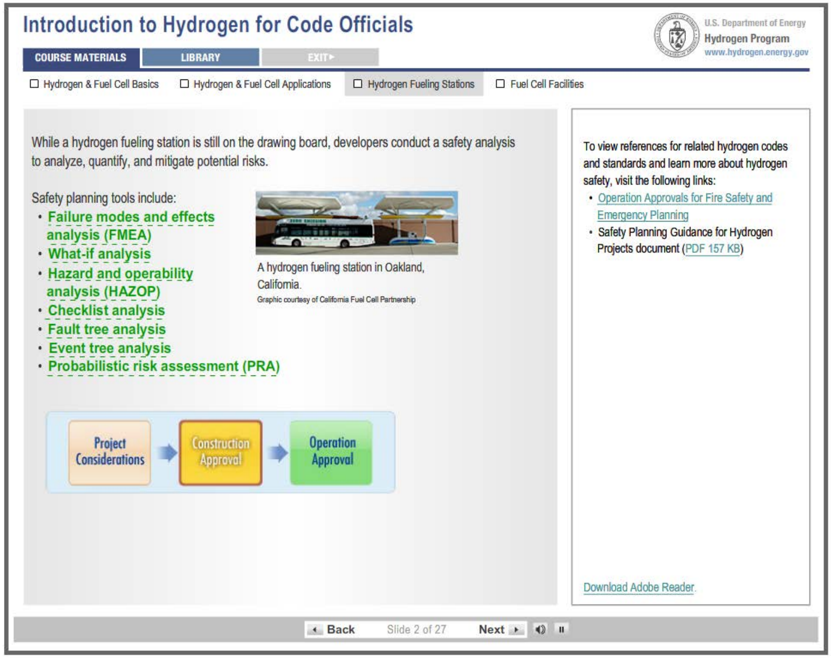
First-of-its-kind software tool for integrating H_2 consequence models w/ QRA models
Includes behavior models & data developed through FY12

Introduction to Hydrogen for Code Officials

Provides an overview of hydrogen and fuel cell technologies, discusses how these technologies are used in real-world applications and discusses the codes and standards required for permitting them.

- Hydrogen and fuel cell basics
- Hydrogen and fuel cell applications
- Hydrogen fueling stations
- Fuel cell facilities

Developed by the National Renewable Energy Laboratory



http://h2tools.org/content/training-materials

Hydrogen Safety Training for Researchers

- **Objectives:** Provide basic hydrogen safety training through an interactive online course
- Laboratory researchers and technical personnel handling hydrogen need basic information on pressure, cryogenics, flammability, asphyxiation, and other risks and precautions for using hydrogen.
- **Six Modules** are included in the course, with a quiz at the end of each module.
  - Course introduction and overview
  - Basic handling precautions for hydrogen use as they relate to Hydrogen's physical and chemical properties
  - Safety issues related to pressure systems
  - Safety issues related to cryogenic systems
  - Overview of emergency response considerations for hydrogen incidents
  - High-Level overview of the codes and standards that apply to hydrogen applications

Sample Screenshot

Class is available at https://h2tools.org/content/training-materials

And Our Newest Resource… HyARC

Hydrogen Analysis Resource Center

- Well-documented, reliable data for use in evaluating hydrogen-related technologies
- Data can serve as the basis for calculations, modeling, and other analytical activities
- Data can be accessed from databases housed in the site itself as well as through links to important websites such as those maintained by the Energy Information Administration (EIA), DOE)Programs, other U.S. Government Agencies, and non-government websites

Data Books

- Transportation Energy Databook
- Biomass Energy Data Book
- Buildings Energy Databook
- Power Technologies Energy Data Book
- NIST Chemistry WebBook

EIA Data and Projections

- Annual Energy Outlook
- International Energy Outlook
- Short Term Energy Outlook
- Monthly Energy Review
- Annual Energy Review

Websites

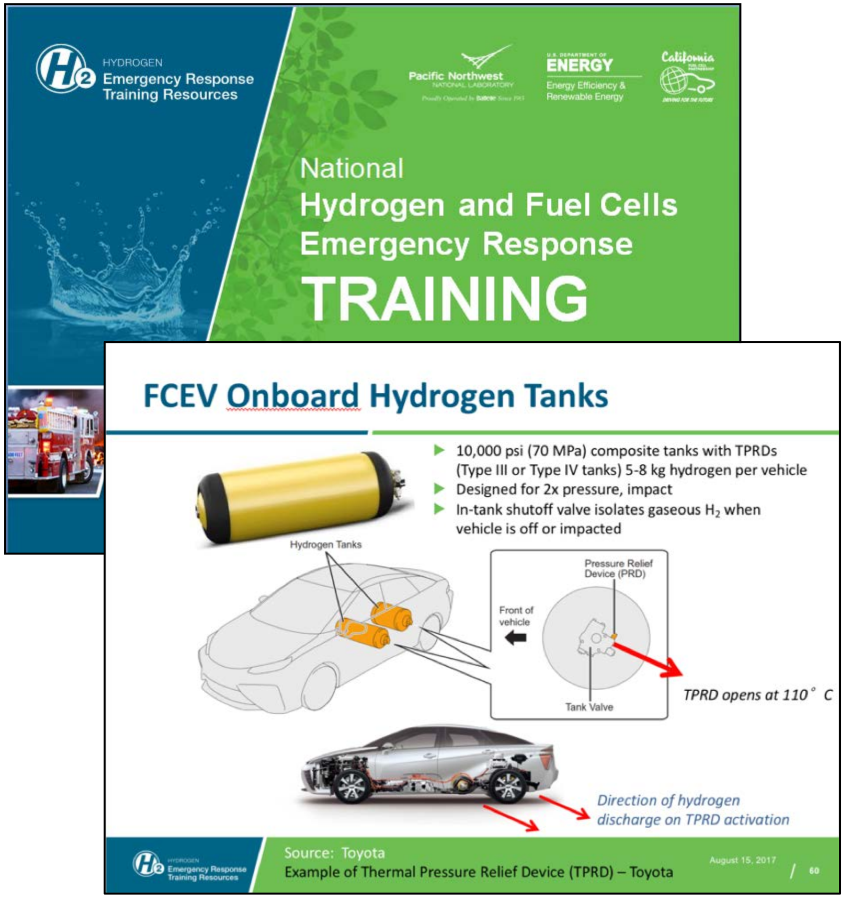
- Hydrogen Program Website
- IPHE Website
- Fuelcells.org Website
- H2Stations.org Website
- Fuel Cell and Hydrogen Energy Association Website
- California Fuel Cell Partnership Website

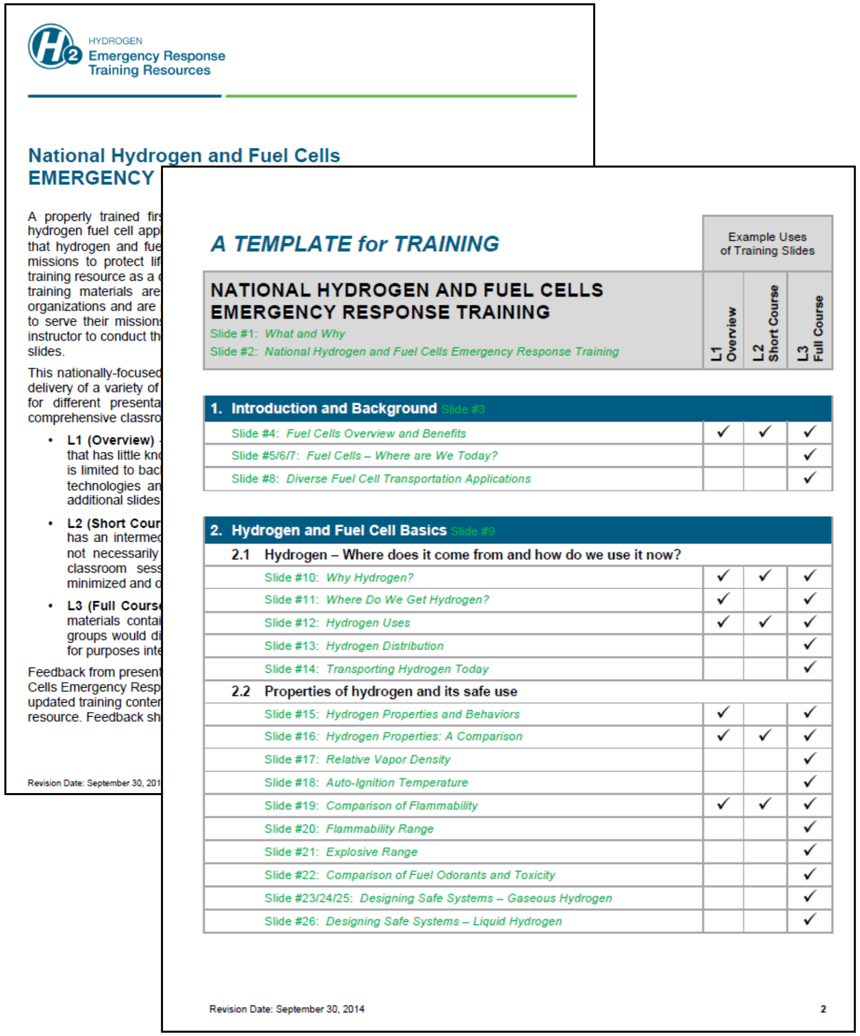
First Responder Hydrogen Safety Training

- **National Goal**
  - Support the successful implementation of hydrogen and fuel cell technologies by providing technically accurate hydrogen safety and emergency response information to first responders
- **Integrated Activities**
  - Online, awareness-level training (https://www.h2tools.org/firstresponder)
  - Classroom and hands-on operations-level training
  - National training resource (enabling trainers) (http://h2tools.org/fr/nt)

A properly trained first responder community is critical to the successful introduction of hydrogen fuel cell applications and their transformation in how we use energy.

National First Responder Training Resource





A TEMPLATE for TRAINING

NATIONAL HYDROGEN AND FUEL CELLS EMERGENCY RESPONSE TRAINING Slide #1: What and Why Slide #2: National Hydrogen and Fuel Cells Emergency Response Training	Example Uses of Training Slides L1 Overview	 L2 Short Course	 L3 Full Course
1. Introduction and Background Slide #3			
Slide #4: *Fuel Cells Overview and Benefits*	✓	✓	✓
Slide #5/6/7: *Fuel Cells – Where are We Today?*			✓
Slide #8: *Diverse Fuel Cell Transportation Applications*			✓
2. Hydrogen and Fuel Cell Basics Slide #9			
2.1 Hydrogen – Where does it come from and how do we use it now?			
Slide #10: *Why Hydrogen?*	✓	✓	✓
Slide #11: *Where Do We Get Hydrogen?*	✓		✓
Slide #12: *Hydrogen Uses*	✓	✓	✓
Slide #13: *Hydrogen Distribution*			✓
Slide #14: *Transporting Hydrogen Today*			✓
2.2 Properties of hydrogen and its safe use			
Slide #15: *Hydrogen Properties and Behaviors*	✓		✓
Slide #16: *Hydrogen Properties: A Comparison*	✓	✓	✓
Slide #17: *Relative Vapor Density*			✓
Slide #18: *Auto-Ignition Temperature*			✓
Slide #19: *Comparison of Flammability*	✓	✓	✓
Slide #20: *Flammability Range*			✓
Slide #21: *Explosive Range*			✓
Slide #22: *Comparison of Fuel Odorants and Toxicity*			✓
Slide #23/24/25: *Designing Safe Systems – Gaseous Hydrogen*			✓
Slide #26: *Designing Safe Systems – Liquid Hydrogen*			✓

Can be downloaded at http://h2tools.org/fr/nt/

Considerations…

- **The Safety Panel's Role**
  - The Safety Panel serves as an asset for an applicant's "continuous and priority attention to safety."
  - Learnings from individual projects benefit the broader safety knowledge base for hydrogen and fuel cell technologies.
- **Lessons Learned**
  - Applicants are asked to share lessons learned based on incidents, near-misses or other learnings during the conduct of this work that can be shared more broadly.
- **Questions/Comments**
  - Applicants may request assistance from or provide input to the safety review team/Hydrogen Safety Panel on any safety-related topic.

Questions and Answers

For additional information…

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Pacific Northwest National Laboratory
(509) 371-7894
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OR VISIT:

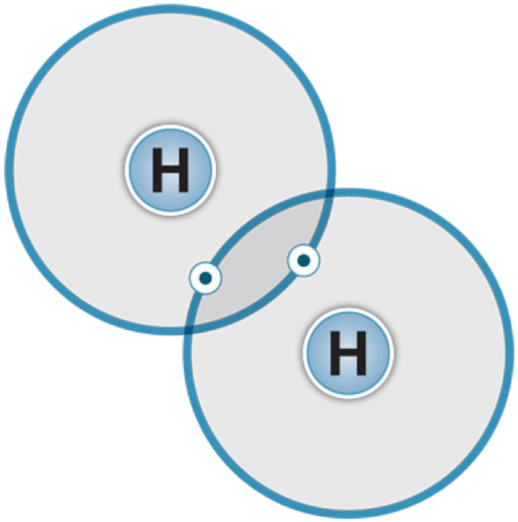
http://h2tools.org

for more Hydrogen Safety related news and the latest resources

Properties of Hydrogen

Hydrogen Properties and Behavior

- **Gas** at ambient conditions
  - Rises and disperses rapidly (14x lighter than air)
  - Flammable range 4-75% in air
- **Liquid** at -423°F (-253°C) – a *cryogen*
  - LH_2 stored at 50 psi in vacuum insulated tanks
  - No liquid phase in compressed gas H2 storage
- **Energy content comparison** :
  - 1kg of Hydrogen ~ 1 gallon gasoline
  - 33.3 kWh/kg hydrogen vs 32.8 kWh/gal gasoline



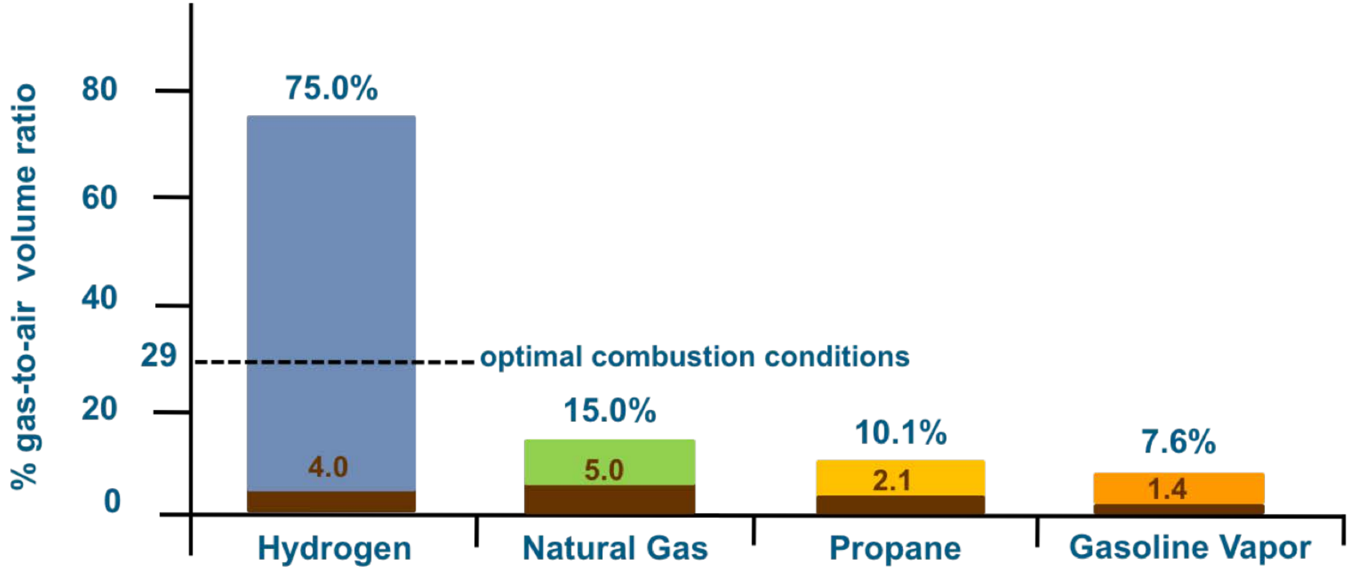
Molecular Hydrogen Model:
2 protons (H+) sharing 2 electrons (e-)

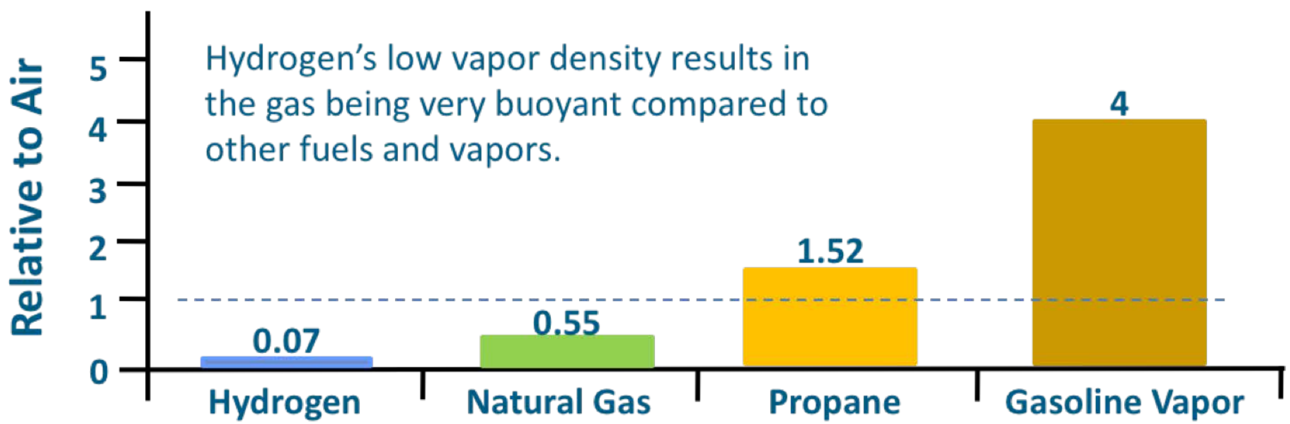
Hydrogen Properties: A Comparison

	Hydrogen	Natural Gas	Gasoline
Color	**No**	**No**	**Yes**
Toxicity	**None**	**Some**	**High**
Odor	**Odorless**	**Mercaptan**	**Yes**
Buoyancy Relative to Air	**14X** Lighter	**2X** Lighter	**3.75X** Heavier
Energy by Weight	**2.8X** > Gasoline	**~1.2X** > Gasoline	**43** MJ/kg
Energy by Volume	**4X** < Gasoline	**1.5X** < Gasoline	**120** MJ/Gallon

Source: California Fuel Cell Partnership

Flammable Range and Vapor Density

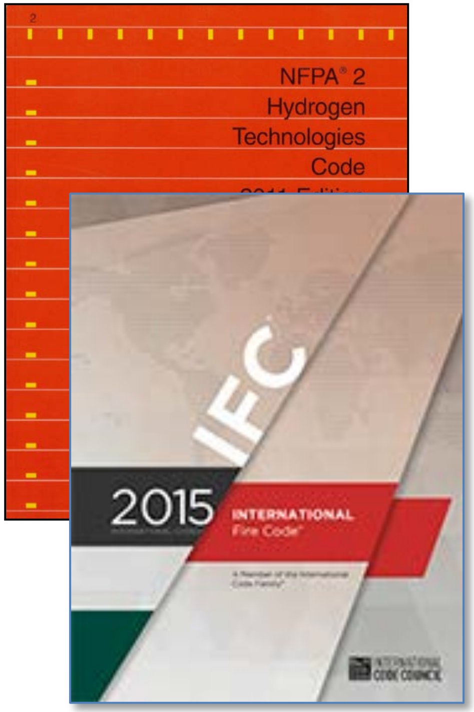




Primary Codes and Standards

Design Consideration: Codes & Standards

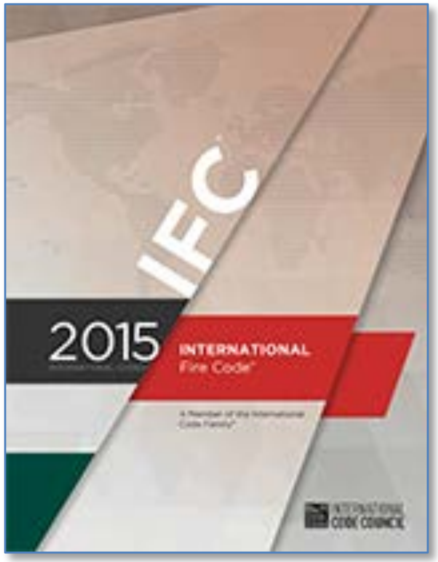
There are many organizations working on codes, standards and guides. https://h2tools.org/fuelcellstandards-view is currently tracking the world-wide development of over 300 hydrogen and fuel cell standards and related documents. Let's focus on the critical infrastructure documents.



- International Fire Code (IFC) - addresses hydrogen applications
- International Building Code (IBC) - general construction requirements
- International Fuel Gas Code (IFGC)
- NFPA 2 Hydrogen Technologies Code
- NFPA 55 Compressed Gases and Cryogenic Fluids Code
- NFPA 70 National Electrical Code
- ASME B31.12 Hydrogen Pipelines and Piping Code - hydrogen piping design

Important IFC 2015 Code References

- **IFC Section 2309** – Hydrogen Motor Fuel-Dispensing and Generation Facilities
- **IFC Chapter 50** – Hazardous Materials - General Provisions
- **IFC Chapter 53** – Compressed Gases
- **IFC Chapter 58** – Flammable Gases and Flammable Cryogenic Fluids
- **International Fuel Gas Code (IFGC) Chapter 7** – Gaseous Hydrogen Systems



Significant changes in the 2015 IFC

"*Compressed hydrogen for use as a vehicular fuel shall also comply with Chapters 23 and 58 of this code, the International Fuel Gas Code and NFPA 2.*"
(IFC 5301.1)

"*Hydrogen motor fuel-dispensing stations and repair garages and their associated above-ground hydrogen storage systems shall also be designed, constructed and maintained in accordance with Chapter 23 and NFPA 2.*" (IFC 5801.1)

The Need for a National Hydrogen Code

With the increased interest in hydrogen being used as a fuel source, the National Fire Protection Association was petitioned to develop an all-encompassing document that establishes the necessary requirements for hydrogen technologies.

- Origin and development of the NFPA 2, Hydrogen Technologies Code
  - Technical committee formed in 2006
  - Focus is to address all aspects of hydrogen storage, use, and handling
  - Draws from existing NFPA codes and standards (extracts from NFPA 52, 55 and 853) (*NFPA 52 hydrogen requirements removed and transferred to NFPA 2*)
  - Identifies and fills technical gaps for a complete functional set of requirements
  - Developed for code users and enforcers
  - Structured so that it works seamlessly with building and fire codes

In the course of this presentation, any comment as to the "meaning" of any part of any NFPA code or standard is only the opinion of the presenter and is NOT to be relied upon as either accurate or official. Only the NFPA may issue a formal interpretation of its codes and standards.

NFPA 2 Scope

The code applies to the use of gaseous and liquefied hydrogen in

- **Storage**
- **Transfer**
- **Production**
- **Use**

including stationary, portable and vehicular infrastructure applications.

Fundamental requirements are provided for

- Storage
- Piping
- Installation
- Handling
- Generation

The Code does not cover

- Onboard vehicle or mobile equipment components or systems
- Mixtures of gaseous hydrogen and other gases with a hydrogen concentration <95% by volume

Contents of NFPA 2, 2016 Edition

	Document Title, *Hydrogen Technologies Code*	
Fundamental Chapters	**Chapter 1, *Administration***	
	Chapter 2, *Referenced Publications*	
	Chapter 3, *Definitions*	
	Chapter 4, *General Fire Safety Requirements*	
	Chapter 5, *Performance-Based Option*	
	Chapter 6, *General Hydrogen Requirements*	
	Chapter 7, *Gaseous Hydrogen*	
	Chapter 8, *Liquefied Hydrogen*	
	Chapter 9, *Explosion Protection*	Reserved
Use Specific Chapters	**Chapter 10, *GH2 Vehicle Fueling Facilities***	
	Chapter 11, *LH2 Fueling Facilities*	
	Chapter 12, *Hydrogen Fuel Cell Power Systems*	
	Chapter 13, *Hydrogen Generation Systems*	
	Chapter 14, *Combustion Applications*	
	Chapter 15, *Special Atmosphere Applications*	
	Chapter 16, *Laboratory Operations*	
	Chapter 17, *Parking Garages*	
	Chapter 18, *Road Tunnels*	
	Chapter 19, *Repair Garages*	
	Annex A	
	Annexes B-M	

Fundamental Safety Considerations

Hydrogen Safety Basics

Hydrogen safety, like all flammable gas safety, relies on five key considerations:

- Recognize hazards and either eliminate or define mitigation measures
- Ensure system integrity
- Provide proper ventilation to prevent accumulation (manage discharges)
- Ensure that leaks are detected and isolated
- Train personnel

Fuel cell backup power connected to a data center

General Considerations

Safety considerations for <u>indoor storage or use</u> of bulk gaseous hydrogen include:

- Buildings should be constructed of noncombustible materials.
- Mechanical ventilation systems should have inlets low to the ground and exhausts at the highest point of the room in the exterior wall or roof. Consideration should be given to providing venting for both normal conditions and emergency situations.
- Hydrogen sensors should be installed at the exhaust within the enclosure.
- Automatic shutoff that activates if a leak or fire is detected in the facility that is being supplied with hydrogen.
- Ignition sources in storage areas should be avoided.
- Classified electrical equipment should be used in close proximity to storage systems.
- Gaseous hydrogen system components should be electrically bonded and grounded.

Hydrogen cylinders and storage tanks should be stored outside at a safe distance from structures, ventilation intakes, and vehicle routes. This applies even while in use. Best practices call for compressed hydrogen bottles supplying a manifold to be located outside, with welded lines to connect to indoor equipment.

Code and Standards: IFC, IBC, IFGC, NFPA 2, NFPA 70

Ventilation

- Proper ventilation can reduce the likelihood of a flammable mixture of hydrogen forming in an enclosure following a release or leak.
  - o At a minimum, ventilation rates should be sufficient to dilute a potential hydrogen leak to 25% of the lower flammability limit (LFL) for all operations and credible accident scenarios.
- Passive ventilation features such as roof or eave vents can prevent the buildup of hydrogen in the event of a leak or discharge, but passive ventilation works best for outdoor installations.
  - o In designing passive ventilation, ceiling and roof configurations should be thoroughly evaluated to ensure that a hydrogen leak will be able to dissipate safely. Inlet openings should be located at floor level in exterior walls, and outlet openings should be located at the highest point of the room in exterior walls or the roof.

Is there a problem here?

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.1, NFPA 2-6.17

Active Ventilation

- If passive ventilation is insufficient, active (mechanical, forced) ventilation can be used to prevent the accumulation of flammable mixtures.
  - ✓ Equipment used in active ventilation systems (e.g., fan motors, actuators for vents and valves) should have the applicable electrical classification and be approved for hydrogen use.
  - ✓ If active ventilation systems are relied upon to mitigate gas accumulation hazards, procedures and operational practices should ensure that the system is operational at all times when hydrogen is present or could be accidentally released.
  - ✓ Hydrogen equipment and systems should be shut down if there is an outage or loss of the ventilation system if LFL quantities of hydrogen could accumulate due to the loss of ventilation. If the hazard is substantial, an automatic shutdown feature may be appropriate.
- Ventilation (passive or active) should be at a rate not less than 1 scf/min/ft^2 (0.3048 Nm^3/min/m^2) of floor area over the area of storage or use.

Be aware that no practical indoor ventilation features can quickly disperse hydrogen from a massive release by a pressurized vessel, pipe rupture, or blowdown.

Code and Standards: IFC 2311.7.1/5808.3.1, IFGC 703.1.2, NFPA 2-6.17

Leak Detection

Hydrogen leak detection systems may be required by the AHJ or may be installed as a means for enhancing safety of the operation. Leak detection can be achieved by:

- **Providing hydrogen (or flammable gas) detectors in a room or enclosure, or**
- **By monitoring the internal piping pressures and/or flow rates for changes that would suggest a leak is present in the system.**
- **Other methods include providing detectors in close proximity to the exterior piping or locating hydrogen piping within another pipe and monitoring the annulus for leaks**.

Regardless of the method used, leak detection systems should, at a minimum, incorporate automatic shutoff of the hydrogen source (and startup of a properly-configured active ventilation system, if present) when hydrogen is detected. For systems designed to monitor hydrogen concentrations in rooms or areas, the leak detection system should also warn personnel with visual and audible warnings when the environment is becoming unsafe. Remote notification should also be considered.

Code and Standards: IFC 5003.2.2, NFPA 2-7.1.22

Leak Detection Design and Performance

Goals for an area hydrogen leak detection system include:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down process equipment to a safe mode
- Control active ventilation
- Activate audible and visual alarms

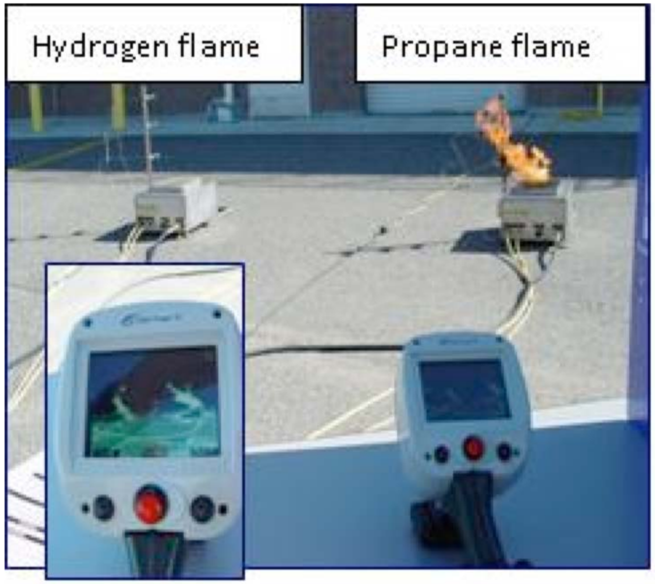
Specific performance considerations:

- Detection sensitivity of +/-0.25% by volume of hydrogen in air
- Response time of 1 second at a concentration of 1% by volume
- The design of a leak detection system must ensure that any leaking hydrogen would pass by the detector.
- The sensitivity of the detector to other gases and vapors should be considered in the selection of the detector and should be explained to personnel.
- A good practice is to set the detectors to alarm at 1% hydrogen by volume in air, which is 25% of the lower flammability limit (LFL). If automatic shutdown is incorporated into the system, manual reset should be required to restart the system.
- Portable gas detectors are valuable for local leak detection. Portable detectors should be used for entry or re-entry into rooms in which an alarm has occurred to ensure that the hydrogen has dissipated.
- Maintenance and recalibration of leak detectors should be performed every 3-6 months and recorded in facility records or manufacturer's instructions.

Checking for Leaks

Hydrogen burns with a pale blue flame that is nearly invisible in daylight. Hydrogen flames also emit low radiant heat, so a person may not feel heat until they are very close to the flame. Best practices include the following:

- A portable flame detector (e.g., thermal imaging camera) should be used if possible.
- Otherwise, listen for venting hydrogen and watch for thermal waves that signal the presence of a flame.
- Use a combustible probe (e.g., broom)
- Always allow enough time for troubleshooting/debugging a monitoring system before it's used.
- Where multiple gases are co-located, always respond in a manner to investigate/ mitigate the most hazardous gas.



Hydrogen and Propane Flames in Daylight
(Photo courtesy of HAMMER)

A Lesson Learned on Hydrogen Leaks

Hydrogen Explosion and Iron Dust Flash Fires in Powdered Metals Plant

- Operators in a powdered metals production facility heard a hissing noise near one of the plant furnaces and determined that it was a gas leak in the trench below the furnaces. The trench carried hydrogen, nitrogen, and cooling water runoff pipes as well as a vent pipe for the furnaces.
- ***Maintenance personnel presumed that the leak was nonflammable nitrogen because there had recently been a nitrogen piping leak elsewhere in the plant***. Using the plant's overhead crane, they removed some of the heavy trench covers. They determined that the leak was in an area that the crane could not reach, so they brought in a forklift with a chain to remove the trench covers in that area.
- Eyewitnesses stated that as the first trench cover was wrenched from its position by the forklift, friction created sparks followed immediately by a powerful explosion. Several days after the explosion, Chemical Safety Board (CSB) investigators observed a large hole (~3x7 inches) in a corroded section of hydrogen vent piping inside the trench.

source: http://www.h2tools.org/lessons

Flame Detection

Hydrogen flames are almost invisible to humans, so thermal and optical sensors are used to detect burning hydrogen.

- To cover a large area or volume, many thermal detectors are needed and should be located at or near the site of a potential fire.
- Optical sensors for detecting hydrogen flames can operate in the ultraviolet or infrared spectral region.

Flame detectors should be installed in certain applications (e.g., NFPA 2 requires them near hydrogen dispensers in hydrogen fueling stations). Detectors should provide a rapid and reliable indication of the existence of a hydrogen flame. The system should also:

- Provide for automatic shut-off and isolation of hydrogen sources
- Shut down the system to a safe mode
- Control active ventilation
- Activate audible and visual alarms
- Control access to areas with high concentrations of hydrogen or active fires

Photo courtesy of HAMMER

Code and Standards: NFPA 2-10.3.1./11.3.3

Electrical Equipment

Specific considerations:

- Fans for active ventilation systems should be provided with a rotating element of nonferrous or spark-resistant construction.
- Equipment or devices should be designed for use in hydrogen service.
- The gaseous hydrogen system should be electrically bonded and grounded.
- Equipment not conforming to NEC requirements must be located outside the area classified as hazardous.

Electrical Equipment Requirements for Bulk Systems

Location	**Classification***	**Distance**
Area containing gaseous hydrogen storage, compression or ancillary equipment	Class 1, Division 2	Up to 15 ft from storage/equipment
Area containing liquefied hydrogen storage	Class 1, Division 2 Class 1, Division 1	Up to 25 ft from the storage equipment, excluding the piping system, downstream of the source valve Within 3 ft from points where connections are regularly made and disconnected
Interior of dispensing equipment	Class 1, Division 2	Up to the support mechanism (anchoring the dispenser) or connection to the ground level
Exterior of outdoor dispensing equipment	Class 1, Division 2	Up to 5 ft from dispenser
Exterior of indoor dispensing equipment	Class 1, Division 2	Up to 15 ft from the point of transfer from floor to ceiling
Outdoor discharge from relief vents	Class 1, Division 1 Class 1, Division 2	Up to 5 ft from the source 5-15 ft from the source
Discharge from relief vents within 15 degrees of the line of discharge	Class 1, Division 1	Within 15 ft from source

* All equipment shall be rated for Group B applications (NFPA 70-500.6).

Code and Standards: IFC 2309.2.3, NFPA 2-10.3.1.16

The Certification Challenge

The scarcity of listed hydrogen equipment places an extraordinary burden on code officials to ensure (approve) that products include the appropriate inherent or automatic safety measures.

Certification presents significant challenges.

- Few systems or equipment that are listed, labeled or certified
- Significant costs since the technology and products are still rapidly changing and each new iteration would require recertification

Development of a Certification Guide
The Hydrogen Safety Panel is developing a guide to assist code officials, designers, owners, evaluators and others with the application of requirements pertinent to the design and/or installation of hydrogen equipment as regulated by the model codes. The scope of the Guideline will be limited to those requirements where the terms *approved*, *certified*, *listed* and/or *labeled* are used.

UL ISO 9001:2008 CERTIFICATION™ Intertek CSA® NRTL/C

A draft version of the Guide is available at:
https://h2tools.org/sites/default/files/Hydrogen_Equipment_Certification_Guide_20151210.zip.

Code and Standards: IFC 2309.2.2, NFPA 2-7.1.3

Outdoor Separation Distances

- Hydrogen cylinders and storage tanks should be stored outside at a safe distance from structures, ventilation intakes, and vehicle routes.
- A ***bulk hydrogen compressed gas system*** is an assembly of equipment that consists of, but is not limited to, storage containers, pressure regulators, pressure relief devices, compressors, manifolds, and piping, with a storage capacity of more than 5,000 scf (141.6 Nm3) of compressed hydrogen gas and that terminates at the source valve.

Photo: h2tools.org

Code and Standards: NFPA 2-7.3.2.3

Outdoor Separation Distances for Bulk Hydrogen Systems

Pressure (psig) Pipe Internal Diameter (in.)	> 15 to ≤ 250 2.07	> 250 to ≤ 3000 0.75	> 3000 to ≤ 7500 0.29	> 7500 to ≤ 15000 0.28
Exposure Group 1 a) Lot lines b) Air intakes (HVAC, compressors, Other) c) Operable openings in buildings and Structures d) Ignition sources such as open flames and welding	40 ft	46 ft	29 ft	34 ft
Exposure Group 2 a) Exposed persons other than those servicing the system b) parked cars	20 ft	24 ft	13 ft	16 ft
Exposure Group 3 a) Buildings of non-combustible non-fire-rated construction b) Buildings of combustible construction c) Flammable gas storage systems above or below ground d) Hazardous materials storage systems above or below ground e) Heavy timber, coal, or other slow-burning combustible solids f) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas g) Unopenable openings in building and structures h) Utilities overhead including electric power, building services or hazardous materials piping systems	17 ft	19 ft	12 ft	14 ft

Source: NFPA 55, 2013 Edition

Code and Standards: NFPA 55-10.3.2

Calculations for Outdoor Bulk Hydrogen System Separation Distances

Pressure (psig)	> 15 to ≤ 250	> 250 to ≤ 3000	> 3000 to ≤ 7500	> 7500 to ≤ 15000
Exposure Group 1 a) Lot lines b) Air intakes (HVAC, compressors, Other) c) Operable openings in buildings and Structures d) Ignition sources such as open flames and welding	0.231d	0.738d	1.105d	1.448d
Exposure Group 2 a) Exposed persons other than those servicing the system b) parked cars	0.12584d −0.47126	0.43616d−0. 91791	0.68311d−1. 3123	0.92909d−1. 6813
Exposure Group 3 a) Buildings of non-combustible non-fire-rated construction b) Buildings of combustible construction c) Flammable gas storage systems above or below ground d) Hazardous materials storage systems above or below ground e) Heavy timber, coal, or other slow-burning combustible solids f) Ordinary combustibles, including fast-burning solids such as ordinary lumber, excelsior, paper, or combustible waste and vegetation other than that found in maintained landscaped areas g) Unopenable openings in building and structures h) Utilities overhead including electric power, building services or hazardous materials piping systems	0.096d	0.307d	0.459d	0.602d

(D) Distance (m)
(d) Diameter (mm)

Source: NFPA 55, 2013 Edition

Selection of Materials

- Materials of construction, including materials used in piping, valves and seals, must be carefully selected to account for their deterioration when exposed to hydrogen at the intended operating conditions.
- The mechanical properties of metals, including steels, aluminum and aluminum alloys, titanium and titanium alloys, and nickel and nickel alloys are detrimentally affected by hydrogen.
- **Exposure of metals to hydrogen can lead to embrittlement, cracking and/or significant losses in tensile strength, ductility, and fracture toughness. This can result in premature failure in load-carrying components.**
- Additionally, hydrogen diffuses through many materials, particularly nonmetals, due to its small molecular size.

Preferred

- Generally acceptable materials include austenitic stainless steels, copper, and copper alloys.

Avoid

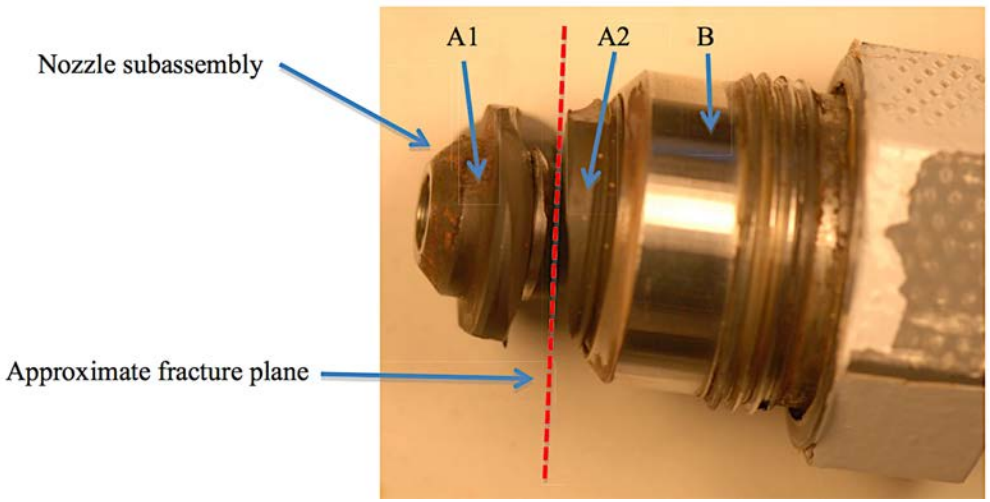
- Nickel and most nickel alloys should not be used since they are subject to severe hydrogen embrittlement.
- Gray, ductile, and malleable cast irons should generally not be used for hydrogen service.

See http://www.h2tools.org/tech-ref/technical-reference-for-hydrogen-compatibility-of-materials for additional guidance.

Codes and Standards: IFGC 5003.2.2.1, IFGC 704.1.2.3, NFPA 2-10.3.1.3

A Lesson Learned on Material Selection

A pressure relief device (PRD) valve failed on a high-pressure storage tube at a hydrogen fueling station, causing the release of hydrogen gas. The gas ignited at the exit of the vent pipe.



- The root cause of the incident was a failed pressure relief valve…
- An extensive metallurgical analysis of the failed valve concluded that **improper material selection and deviations from valve production processes led to the valve failure**.

The good news… There were no injuries and very little property damage. The corrugated roof on an adjacent canopy over a fueling dispenser was slightly singed by the escaping hydrogen flame, causing minimal damage.

Source: http://www.h2tools.org/lessons

Piping Layout and Design

Hydrogen piping systems should be designed in accordance with the applicable codes and standards and to:

- Minimize leaks through the use of welded joints where possible
- Piping should not be concealed and arranged to ensure that personnel will be able to easily reach joints and fittings (to check for leaks).
- Prevent or reduce the chance of personal injury (i.e., contact with cold surfaces, head impact, tripping hazards, etc.)
- Minimize stresses (structural and thermal) in piping components and connected equipment
- Provide proper sizes and settings of pressure relief devices
- Include properly labeled shutoff valves at safe locations

Flow restrictors, such as orifice meters, in the supply line are an effective means of limiting the supply flow rate and controlling leakage rate.

Piping should be labeled to indicate content, flow direction, and design and test pressures.

Vent Lines

Vent lines for hydrogen (including pressure relief lines and boil-off from cryogenic systems) should be vented to a safe outside location. The vent should be designed to prevent moisture or ice from accumulating in the line. The vent system should:

- be leak tight
- avoid air intrusion or be designed to handle the possibility of an explosion inside the piping
- be unobstructed and protected from the weather
- safely release the unused hydrogen above the facility roof or at a remote location
- be designed to carry the excess flow of the venting gas or liquid

Codes and Standards: IFGC 704.1.2.3, ASME B31.12, CGA G5.5

Working with First Responders

Preplanning

- Facility owners and first responders should work together to perform preplanning activities. This should include a tour of the hydrogen facilities with focused attention on safety features and emergency shutoffs.

Training

- Training of emergency response personnel should be a high priority to ensure that these personnel understand how to properly respond to a hydrogen incident.
- A variety of resources are available to assist with this training (and discussed in later slides).

Equipment

- A hydrogen fire is often difficult to detect without a thermal imaging camera or flame detector. First responders should have one available for their use.

Photo: Volpentest HAMMER Federal Training Center

Safety Considerations for Liquid Hydrogen

This presentation was primarily focused on gaseous hydrogen systems and equipment. Cryogenic liquid hydrogen storage and supply systems offer additional hazards. General safety considerations for the use of cryogenic liquid are listed below.

- Due to its extremely low boiling point, liquid hydrogen can cause serious frostbite and hypothermia.
- Ice formation on vents and valves could cause them to malfunction.
- Condensed air could result in oxygen enrichment and explosive conditions near a liquid hydrogen storage system.
- Accidental air leakage into a liquid hydrogen storage vessel (e.g., from inadequate purging) will result in the introduction of moisture. The water will form ice, which may plug lines or cause instruments to malfunction.
- Continuous evaporation generates gaseous hydrogen and an increase in pressure inside a liquid hydrogen storage vessel if not properly released.

A liquid hydrogen release will look similar to this liquid nitrogen release.
(Photo courtesy of Scott Stookey)

- If a liquid hydrogen leak or spill occurs, a hydrogen cloud could flow horizontally for some distance or even downward, depending on the terrain and weather conditions.

Concluding Thoughts

- Safe practices in the production, storage, distribution and use of hydrogen are essential for deployment of hydrogen and fuel cell technologies. ***A significant incident involving a hydrogen project could negatively impact the public's perception of hydrogen systems as viable, safe, and clean alternatives to conventional energy systems.***

- Hydrogen CAN be used safely. However, because hydrogen’s use as a fuel is still a relatively new endeavor, the proper methods of handling, storage, transport and use are often not well understood across the various communities either participating in or impacted by its demonstration and deployment. Those working with hydrogen and fuel cell technologies should utilize the online resources discussed in this presentation to become familiar with the technology.

- The IFC, IFCG and NFPA 2 provide fundamental requirements for the use of hydrogen and fuel cell technologies. Online resources are available to help code officials and project proponents better understand and apply the necessary safe practices for the successful deployment of this technology.

Questions and Answers

For additional information…

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for more Hydrogen Safety related news and the latest resources